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STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF CONSTRUCTION
OFFICE OF TRANSPORTATION LABORATORY

NONWOVEN GEOTEXTILE FABRICS: EVALUATION AND SPECIFICATION FOR SUBDRAINAGE FILTRATION

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Study Supervised by .... R. A. Forsyth, P.E.
R. H. Prysock, P.E.

Principal Investigator .... T. P. Hoover, P.E.

Technical Assistants .... F. E. Lienert, Jr.
M. E. Nolan

Report Prepared by .... T. P. Hoover, P.E.

Eric F. Nordlin

ERIC F. NORDLIN
Acting Chief, Office of Transportation Laboratory

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16. ABSTRACT

This project developed techniques for evaluating the Flow Capacity (FC) and the Plugging Flow Capacity (PFC) of nonwoven geotextile fabrics. These parameters can be specified for given fabric installations and will provide fabrics of suitable flow capability and filtration potential without excessive plugging. Recommended specifications and test methods for FC and PFC, developed during this study, are included as interim guidelines, to be evaluated and refined through applied use.

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CONVERSION FACTORS

English to Metric System (SI) of Measurement

Quantity	English unit	Multiply by	To get metric equivalent
Length	inches (in)or(")	25.40 .02540	millimetres (mmm) metres (m)
	feet (ft)or(')	.3048	metres (m)
	miles (mi)	1.609	kilometres (km)
Area	square inches (in^2)	6.432×10^{-4}	square metres (m^2)
	square feet (ft^2) acres	.09290 .4047	square metres (m^2) hectares (ha)
Volume	gallons (gal)	3.785	litres (l)
	cubic feet (ft^3)	.02832	cubic metres (m^3)
	cubic yards (yd^3)	.7646	cubic metres (m^3)
Volume/Time (Flow)	cubic feet per second (ft^3/s)	28.317	litres per second (l/s)
	gallons per minute (gal/min)	.06309	litres per second (l/s)
Mass	pounds (lb)	.4536	kilograms (kg)
Velocity	miles per hour (mph) feet per second (fps)	.4470 .3048	metres per second (m/s) metres per second (m/s)
Acceleration	feet per second squared (ft/s^2)	.3048	metres per second squared (m/s^2)
	acceleration due to force of gravity (G)	9.807	metres per second squared (m/s^2)
Weight Density	pounds per cubic (lb/ft^3)	16.02	kilograms per cubic metre (kg/m^3)
Force	pounds (lbs) kips (1000 lbs)	4.448 4448	newtons (N) newtons (N)
Thermal Energy	British thermal unit (BTU)	1055	joules (J)
Mechanical Energy	foot-pounds (ft-lb) foot-kips (ft-k)	1.356 1356	joules (J) joules (J)
Bending Moment or Torque	inch-pounds (ft-lbs) foot-pounds (ft-lbs)	.1130 1.356	newton-metres (Nm) newton-metres (Nm)
Pressure	pounds per square inch (psi)	6895	pascals (Pa)
	pounds per square foot (psf)	47.88	pascals (Pa)
Stress Intensity	kips per square inch square root inch (ksi $\sqrt{in}$)	1.0988	mega pascals $\sqrt{metre}$ (MPa $\sqrt{m}$)
	pounds per square inch square root inch (psi $\sqrt{in}$)	1.0988	kilo pascals $\sqrt{metre}$ (KPa $\sqrt{m}$)
Plane Angle	degrees (°)	0.0175	radians (rad)
Temperature	degrees fahrenheit (F)	$\frac{tF - 32}{1.8} = tC$	degrees celsius (°C)

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INTRODUCTION

The use of woven and nonwoven fabrics (geotextiles) in civil engineering applications is undergoing rapid expansion. While sand and gravel are becoming more expensive because of increased hauling costs, manufactured fabrics are becoming more economical. They have had increasing application for soil reinforcement, erosion control on levees, erosion control on major construction projects (environmental), and as filter elements in subdrainage systems. At a time when mineral aggregates are becoming scarce and increasingly expensive, a wide range of woven and nonwoven fabric types are being developed and marketed. There exists, however, only limited documented information on their engineering properties, appropriate test methods, and the criteria for geotextile installation. Most investigations of record have dealt with the textile properties rather than with the application requirements. Many of the investigations have been limited to woven fabrics or have been sponsored by companies with vested interests in promoting their products.

The earliest extensive use of geotextiles in the U.S. was by the U.S. Corps of Engineers for levee protection. Woven fabrics were used as a filter element between silty soil embankments and rock facings(1). More recently the U.S. Forest Service has used large quantities of filter fabrics for road subgrade reinforcement, subdrainage elements and for erosion control(2). Many state highway departments have used geotextiles as filter elements in pavement subdrainage systems(3) and to reduce reflection cracking in asphalt pavement overlays. More extensive usage of geotextiles by state agencies is anticipated following the development of appropriate test methods and specifications for specific applications.

In earth reinforcement, engineering fabrics act as separators between fine subgrade soils and overlying granular layers. This separation prevents intrusion of the subgrade into the overlying layers and dispersion of the granular overlying material into the fine grained subgrade. At the same time, fabrics may provide an element of tensile strength which increases the load supporting effectiveness of overlying granular layers.

In erosion control applications, fabrics are used to minimize piping of fine material from behind coarse stone used as riprap. Fabrics are also used as silt barriers to reduce the downslope sedimentation affects associated with the erosion of exposed soils during construction.

In subdrainage applications, fabrics are used in place of graded aggregate filters to maintain required flow rates without clogging, while preventing fines from passing through and plugging outlet systems.

Filters are required wherever coarse aggregates or aggregate conduit systems are used to drain erodible soils. Historically, these filters have been the Terzaghi "inverted filter" type described by Cedergren(4). The "inverted filter" utilizes a coarse layer of aggregate for removing water. This layer is surrounded by an appropriate finer graded filter which prevents the intrusion of fine grained soils into the drainage layer. Intrusion of fines causes clogging and a reduction of permeability within the drainage layer and results in soil loss from the surrounding drainage area. Current gradation design for filters is generally based on criteria developed by Bertram(5). These criteria are:

D_{15} of the filter is less than $5(D_{85})$ of the soil

D_{15} of the filter is more than 4 and less than 20 times D_{15} of the soil.

The third criterion developed by the Army Corps of Engineers(4) relates the D_{50} sizes as follows:

D_{50} of the filter is less than $5(D_{50})$ of the soil

In the above criteria, D_x is the size particle (D), of which x percent of the total sample is finer than D. D_x is commonly derived from a plot of percent passing a given screen size as determined from a conventional mechanical analysis.

Since graded aggregate filters can dissociate when they are used for draining a very fine sand, several layers may be required to function properly. Due to the structural integrity of the man-made geotextile filter, it will not dissociate and may be installed in a single thin layer between drainage aggregate and the soil to be filtered.

A single layer filter permits using a higher percentage of the more economical coarse material and at the same time, by using a thinner section, a lower total volume of rock which results in significant savings. It should be emphasized, however, that the same area of contact is required when using either aggregate or geotextile filters. Geotextile filters present a potentially simpler and time saving type of installation which can reduce construction costs. Further, the use of geotextiles rather than gravel filters can preclude the possibility of faulty installation.

Mineral aggregates, when used as filters, can be graded to achieve the most desirable pore sizes. Geotextiles, on the other hand, generally have a relatively constant pore size within each brand, although some (especially the nonwovens) have a range of pore sizes. The pore size may vary radically, however, from brand to brand. If a filter fabric has a small pore size, it will impede flow to a greater extent than will a fabric with a larger pore size. However, it will also reduce soil loss where the soil contains substantial fractions between the pore sizes of the two fabrics.

Effective use of fabrics requires improvement of the specifications now used for subdrainage applications. Current specifications for nonwoven filter cloth relate largely to strength, permeability and toughness. They do not consider the filtering capabilities of the cloth or its capacity to resist clogging. While strength and toughness are necessary to permit handling and installation, filtration without clogging is the paramount function of the geotextile. Therefore, this function should be reflected in test methods and fabric specifications. Furthermore, specifications should address water permeability, or more importantly, flow capacity and the interrelationships of the fabric and the soil grain sizes that can be filtered.

This project was initiated to develop suitable specifications for the use of nonwoven geotextiles in subdrainage applications.

The objectives of this project were to:

1. Develop a test method for evaluation of the pore size of a nonwoven filter fabric.

2. Develop a test method to determine water permeability and filtering capability of fabrics.

3. Define a relationship between pore size and the grain size of the material to be filtered, including any restrictions which might be necessary to permit filtration without piping or filter blockage.

4. Synthesize parts 1 through 3 and appropriate quality control tests into a suitable specification for subdrainage fabrics.

CONCLUSIONS AND RECOMMENDATIONS

Results of this study indicate that sieve testing geotextiles for pore size is unreliable. The sieving technique is inaccurate and nonrepeatable when glass beads smaller than a 60 to 100 sieve size range are used. With particles of this small size, other forces are stronger than the gravitational forces available to do the sieving.

Accurate values for permeability are difficult to determine for single layers of fabric. Because of the very small values of thickness used for sample length in normal permeability calculations, the results are highly variable for single layers of geotextiles. Minor errors in thickness measurement can make calculated permeabilities vary by order of magnitude. Realistic evaluations can be obtained with multiple layers. However, multiple layer evaluations do not reflect the general method of field application. Also, the high rates of permeability associated with these fabrics result in turbulent flow, which is not consistant with the assumptions for permeability calculations. It is therefore recommended that the flow per unit area for a single thickness of fabric (Flow Capacity, FC) be used to evaluate the flow capability of geotextiles. A recommended test method for determination of Flow Capacity is included as Appendix A.

In addition to the Flow Capacity, some measure of filtration must be made. The Plugging Flow Capacity (PFC) as developed in this study can be used to evaluate a fabric's potential for filtration and plugging. Knowing the soil grain size distribution, the PFC for the D_{85} grain size can be used to evaluate filtration potential. The PFC for the D_{15} and D_{50} grain sizes can be used to evaluate plugging potential. The recommended test method for PFC and its applicability are presented by Appendix B. Normally all PFC values (PFC_{15}, PFC_{50}, and PFC_{85}) should be more than 10 times the soil permeability when both the PFC and k values are in the same units.

When draining coarse grained sandy material, the Plugging Flow Capacity need not be evaluated in great detail. The large grain sizes are readily filtered. Even so, these soils could migrate into drainage systems if some manner of filtration were not provided.

Fabric filters require some specific design for each job. An understanding of the objective of application, not just the mechanics of installation and specification, should be available to the designer.

It is recommended that further investigation be undertaken to develop acceptance criteria and to determine the potential for broader, less individualized specifications. A PFC-FC specification based on general soil types is believed to be possible.

IMPLEMENTATION

The specification developed during this study should be used in future California Department of Transportation (Caltrans) projects which use geotextiles as subdrainage filters.

The Transportation Laboratory (TransLab) will continue to perform the tests, evaluate the results and provide assistance in specific applications of geotextiles.

PORE SIZE INVESTIGATION

The intent of this phase of the investigation was to determine the quickest, most reliable way to evaluate the size of the openings between the fibers used to fabricate the nonwoven fabrics. A part of the initial work plan included the introduction of known weights of sized glass beads (five grams of eight different sizes of beads) as a single sample to be sieved through the fabric. After the sieving operation, the weight of the beads passing through the fabric and reaching the pan would be recorded. If this weight was an integer multiple of five, then the sieve size associated with the fabrics sieving ability could be readily determined. If not, a sieve analysis of the pan material would be required to determine the sieving ability of the fabric being tested.

This concept was tested using standard 8-inch copper sieves and glass beads which were sieved into the sizes to be used in the testing program. The overall size range to be used was between the 100 and 400 sieve sizes. The beads were sieved from the six different size groupings purchased. The size ranges of beads as received and the sizes for use in the testing procedure are presented in Table I.

TABLE I

Size Ranges of Glass Beads as Received

Letter Designation	U.S. Sieve Size Passing	Retained	Nominal Size Inches	Micron Range
MS-H	60	100	.0097-.0058	250-149
MS-MH	70	140	.0082-.0041	210-105
MS-M	100	200	.0058-.0029	149-74
MS-ML	140	270	.0041-.0021	105-53
MS-L	200	325	.0029-.0017	74-44
MS-XL	270	1,000	.0021-.0005	53-10

Gradations to be Used in Testing
(Retained Upon Sieve Sizes)
100, 140, 170, 200, 230, 270, 325, 400, PAN

In preparation for the fabric testing, the sieving accuracy was checked. The method for checking the first sieving involved the use of five grams of each of the retained sieve sizes as a single charge on the top sieve with a 15 minute shaking cycle. This cycle is consistent with California Test 202, Method of Test for Mechanical Analysis of Soil, as was the sample size. The results of this sieving were highly unsatisfactory. Each sieve should have contained five grams of glass beads after sieving. This was not the case as shown by representative data from the check sieving (Table II).

Subsequent attempts revealed that humidity had an influence on the results. In an effort to overcome this influence (particle aggregation due to water surface tension), the sieving technique was altered to include 20 grams of a plus-twenty sieve size dessicant on each sieve. The beads were resieved with the addition of the dessicant which improved the repeatability of the method but did not yield sufficient accuracy to allow the establishment of a test method. Representative data of the check sieving with a dessicant are included in Table III.

A wet sieving process was also investigated. It proved to be so cumbersome and showed so little potential that a full series of tests was not run. No data from this testing were retained.

Subsequent to laboratory testing, it was concluded that difficulties can be expected when sieving sizes smaller than a 100 sieve using glass beads as the inert standard soil model. It appears that the inter-particle forces are more significant than the gravitational forces when sieving these very small particles. Sieving therefore does not appear to be a dependable technique for evaluation of pore sizes in geotextile fabrics.

TABLE II

Sieving of Sized Beads

Run No.	Sieve Size 100	140	170	200	230	270	325	400	PAN
1	0.9	7.0	10.1	3.4	6.0	8.5	2.0	6.1	1.0
2	4.3	3.0	8.7	4.0	8.4	2.6	6.0	1.0	7.0
3	3.2	7.0	4.0	8.4	2.0	9.3	1.0	4.1	6.0
4	6.1	2.0	8.0	3.6	4.2	6.1	8.2	2.6	4.2
5	6.3	4.0	2.0	7.5	7.2	4.0	1.4	7.2	6.4

Numbers represent weight of beads in grams retained on sieve.

TABLE III

Sieving of Sized Beads with Dessicant Added(1)

Run No.	Sieve Size 100	140	170	200	230	270	325	400	PAN
1	2.1	7.1	4.8	6.2	3.2	8.0	4.1	6.3	3.2
2	2.0	7.3	5.0	6.3	3.1	7.9	4.1	6.3	3.0
3	2.3	7.1	4.8	6.3	3.1	8.0	4.2	6.3	2.9
4	2.2	6.9	4.9	6.3	3.1	8.0	4.1	6.4	3.1

(1) 20 grams of dessicant placed on each sieve.

Numbers represent weight of beads in grams retained on sieve.

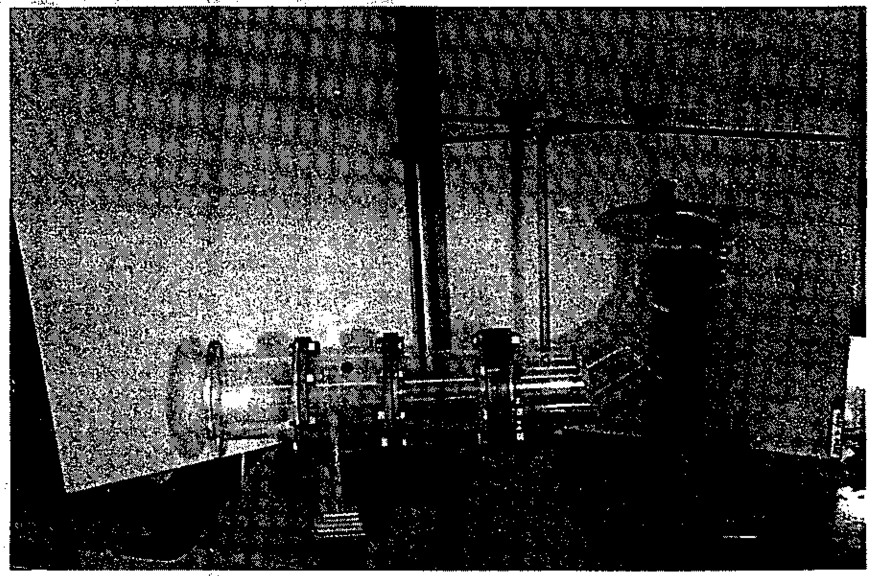
PERMEABILITY AND FILTRATION

Permeability

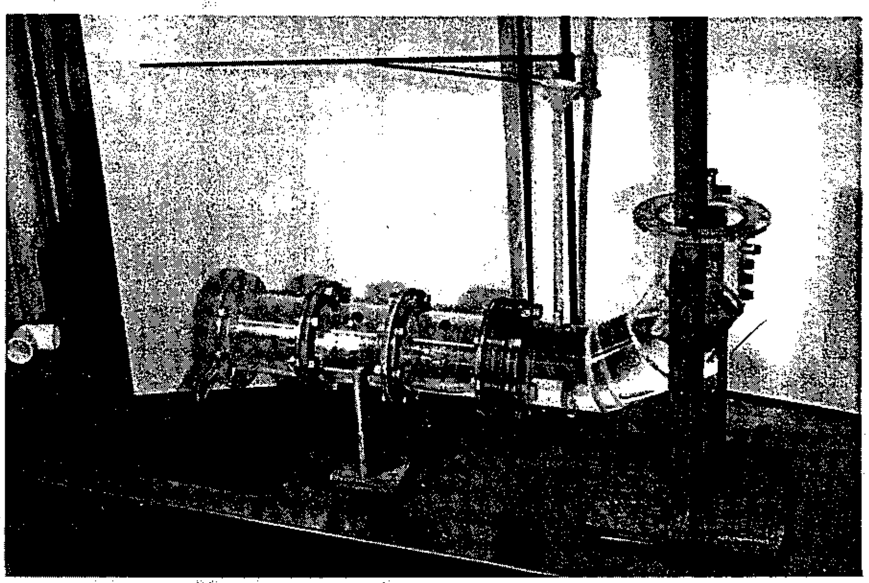
The initial objective of this phase of the study was to determine if the permeabilities of the various geotextiles were readily measureable constant properties or if the fabrics exhibited variabilities such that their permeability was not a meaningful parameter. As the testing began, it was found that the fabric thickness was highly variable and that small variations in the measurement of the thickness had signficant effects on the permeability calculated. In view of this and the fact that fabrics are normally to be installed in a single thickness, (one-side-submerged condition), it was concluded that the flow capacity per unit area would be a more meaningful parameter than would conventional permeability. Therefore, subsequent testing emphasized flow capacity per unit area. Flow Capacity is calculated the same way as permeability except the sample length is single unit, representing one fabric thickness regardless of its actual measured thickness. The Flow Capacity calculation is further defined in Appendix A.

In addition to the Flow Capacity concept, the material should be tested under the conditions of application, i.e., not submerged on both sides, but rather free draining on the downstream side.

Testing was done with a clear acrylic horizontal permeameter (Figure 1). The clear medium was used to allow observations of flow characteristics. The sample size, five inches in diameter, was selected to overcome some of the problems which result from small scale tests in



A. Permeameter with assembled sample holder, no water inlet.



B. The permeameter with steady state flow.

FIGURE 1 CLEAR ACRYLIC HORIZONTAL PERMEAMETER which the discrete fibers or pores may control the test results rather than the general fabric parameter range. Observed test results do not always reflect these controls. The five inche size is also compatible with testing aggregate-fabric systems.

The flow for the permeameter (high volume, low pressure) was provided by an overflow head tank system supplied by tap water (45 psi) through a 3/4-inch line. The outflow from the head tank to the permeameter is at 2 psi$\pm$ through 1 1/2 inch plastic pipe providing a relatively calm nonturbulent high volume flow that can be used in permeability testing. A tap water supply without the head tank provides high velocity turbulent water, unsuitable for testing the fabric.

De-aired water was not used for two reasons. De-aired water normally is not encountered in the field and the air in water appears to be significant only in flow studies greater than 10 to 15 hours.

Six different fabrics were tested: Two spun-bonded fabrics, three needle-punched fabrics, and one hybrid fabric which is both spun-bonded and needle punched. They were evaluated under three different flow conditions: (1) open ended free draining, (2) both sides submerged, and (3) with rock on the downstream side.

Because of the high permeabilities associated with these types of filters and the high velocities within and adjacent to the fabrics, flow at these points is not laminar. Thus the general concepts associated with permeability do not necessarily apply. Based upon the limited testing program undertaken during this project (324 data points) there does appear to be a general relationship between head and Flow Capacity. As the head increases the Flow Capacity decreases, possibly due to entrance losses at the pores and velocity losses through the microchannels of the fabrics. Because of the inherent variability of the non-woven fabrics tested and the scale of the testing, the Flow Capacity tends to vary, but only within a given order of magnitude. Table IV presents representative data for two fabrics.

It was also determined that some fabrics require substantially more head to initate flow than others. The spun-bonded and woven fabrics require more head than do the needle punched fabrics. These planer fabrics seem to require some minimum head to overcome the water surface tension, which allows the water to span the small size pores. The needle punched fabrics do not exhibit this property.

Based upon these findings, it appears that Flow Capacity determinations should be used to insure that filters are at least one order of magnitude more permeable than the soils to be drained. Also, Flow Capacity should be determined in the lowest flow capacity system, the open-ended-downstream, free draining condition, to simulate the field condition which yields the least flow. The nonwoven fabrics tested exhibit substantial variations in their Flow Capacity. They do in general, however, have Flow Capacities much greater than soils which would require filtration. As a specification requirement, Flow Capacity should be used to guarantee minimum adequate flow capability for handling the

TABLE IV

Flow Capacity Data

Fabric Type	Test Type(1)	Head Inches	Time Seconds	Flow Capacity (ft/day)
Needle	R	9.45;10.35	28.9;29.5	1709;1528
Punched	O	6.00;13.4	12.8;12.6	6076;2764
	S	2.05; 2.1	24.6;24.7	9254;8997
Spun	R	9.20;5.95	34.2;44.8	1483;1751
Bonded	O	10.90;8.90	14.3;18.4	2994;2850
	S	0.90;2.60	82.8;39.5	6262;4544

Diameter = 4.95 inches; Catch Volume = 5.41 gallons.

(1) R = Aggregate filled drain channel
O = Open ended drain channel
S = Submerged outlet

available flow with an allowance for flows in excess of the maximum expected. A suggested method of application is presented in the Proposed Specification section of this report.

Filtering Ability

Filtering ability was to be an evaluation of the Flow Capacity as previously defined in conjunction with glass beads. The fabric was to have its initial Flow Capacity evaluated. Then during steady state flow, glass beads would be introduced into the stream. The effects of the glass beads, flow reduction and head rise, would be evaluated. Filtration would be indicated by a resulting head rise which, however, would not necessarily reduce the flow rate. A head rise combined with a flow reduction would indicate a possible plugging rather than a filtering effect.

The testing provided for the introduction of six grades of glass beads into the established flow of a given fabric. The sizes used are those listed in Table I under "as received". The beads were injected into the stream in five gram lots in both increasing and decreasing size ranges. The Flow Capacity calculated after glass bead introduction is the Plugging Flow Capacity. Sample calculations are included in the test method, Appendix B.

The test method presented in this report should be used for individual fabric selection based upon the grain size distribution of the soil to be filtered. Glass beads of a size range equal to the D_{85}, D_{50} and D_{15} sizes of the soil to be filtered should be introducted, on separate samples, into the flow stream of the permeameter with the cloth to be evaluated. The choice of the D_{85} size is based upon the filter cake theory(6) and the concepts of Bertrum(5). The D_{50} size is used as a check for excessive plugging potential as is the D_{15} size. The D_{50} Plugging Flow Capacity is indicative of the order of magnitude expected for flow through the filter system. The D_{15} Plugging Flow Capacity is used to determine whether or not filtration takes place or piping of the fines occurs. If filtration takes place, the Plugging Flow Capacity must be greater than the soil permeability. Piping of the D_{15} size is not usually significant except that the downstream drainage must be able to function with some minor silt intrusion. After introducing the glass beads, a head rise should be noted. Filtration results in some portion of the flow area being covered by glass beads. No head rise indicates piping and a substantial probability that the fabric will not filter the size associated with no head rise. In addition to the head rise, the Flow Capacity should be observed. After adding the beads the Flow Capacity should still be of such magnitude as to permit free drainage in all cases. The Flow Capacity should be at least five, and preferably 10 times the permeability of the soil to be drained. The amount of head rise resulting from filtration varies from fabric to fabric. Therefore, no quantitative values for allowable or required head rise have been suggested to date. An estimate of the appropriate head rise can be made by experimentally determining a value for head rise using various sized glass beads known to be filtered by the given fabric. Even though adequate flow capability is the primary concern, absolute values of head should be minimized or excessive pore pressures may develop. Because of the inherent variability of the fabrics, a range of head rise should be determined.

PORE SIZE - GRAIN SIZE RELATIONSHIP

Since fabric pore sizes could not be determined, a relationship between fabric pore size and soil grain size could not be established. Originally it was believed that criteria similar to that used when sizing aggregate for use with perforated pipe could be developed. The perforation size would be represented by the pore size and the aggregate size would correspond to the soil size. The criteria would facilitate design of filters that would not plug with single grains as a slot or hole might, while still filtering the required sizes of particles. Since the above concept could not be quantified, the plugging phenomenon was addressed in the filtration portion of the project.

The plugging aspect was reevaluated concurrently with the filtering ability through the use of glass beads introduced into the flow stream of a fabric being tested for Flow Capacity. In testing for filtration a head rise must be realized by introducing glass beads equivalent to the D_{85} and D_{50} sieve sizes of the soil to be filtered. The plugging aspect was evaluated by noting if the flow capacity was sufficiently reduced to inhibit free drainage when beads representing the D_{85}, D_{50}, and D_{15} sizes were introduced. The Flow Capacity should still be at least 5 to 10 times greater than the permeability of the soil to be drained. In addition, the introduction of D_{15} size beads should produce a head rise no greater than that resulting from the introduction of the D_{50} or D_{85} size beads. This filtration-plugging test procedure and its applicability require further study before acceptance criteria can be established.

PROPOSED SPECIFICATION

The following specification for Geotextiles as subdrain filters is based upon this study and Caltrans' experiences over the past 5 years. This application dependent type of specifcations makes it more difficult for the designer to use a universal fabric on a job, but it also provides the optimum fabric for any given installation.

Consideration has been given to both functional parameters and those requirements necessary for installation. This specification covers only the materials parameters and requires additional installation and qualitative support specifications, such as lapping or stitching requirements and subgrade preparation.

Proposed Geotextile Subdrain Filter Specification

Parameter	Application: Highway Edge Drains	Smooth Stable Trenches <10'	Rocky, Caving Trenches>10'	Stabilization Trenches	Blanket Drains Ground Water	Blanket Drains Surface Water
1) Weight/sq.yd. ASTM D-1910	4.0	4.0	5.0	4.0	4.0	4.0
2) Tensile Strength/lin. in. ASTM D-1682	50	90	150	100	100	50
3) Elongation percent ASTM D-1682	10	30	40	30	30	10
4) Toughness (No. 2(No.3) Example (100 lb/in)(50%) = 5000	3000	4000	8000	4000	4000	3000
5) Flow Capacity(1) Proposed Calif. Method(2)	10 k_{soil}(3)	10 k_{soil}	10 k_{soil}	10 k_{soil}	10 k_{soil}	10 k_{above}(4)
6) Plugging Flow Capacity(1) Proposed Calif. Method(2)	5 k_{soil}	5 k_{soil}	5 k_{soil}	10 k_{soil}	5 k_{soil}	10 k_{above}

(1) These parameter limits are determined by the permeability of the soil to be filtered. The Flow Capacity should be at least 10 times the permeability of the soil. The Plugging Flow Capacity should be at least 5 times and as much as 10 or more times the soil permeability. These parameters are specified as minimum values of flow per unit area.

(2) See appendices for methods.

(3) k_{soil} is the soil permeability.

(4) k_{above} is the minimum permeability of the drainage path above the filter.

REFERENCES

1. Carthage Mills case history summary records.

2. Steward, J., Williamson, R. and Mohney, J., Guidelines For Use Of Fabrics In Construction And Maintenance of Low-Volume Roads, Report No. FHWA-TS-78-205, USDA, Forest Service, Portland, Oregon, June 1977.

3. Questionnaires from: Alabama, Illinois, and New York Departments of Transportation.

4. Cedergren, H. R., Seepage, Drainage, and Flow Nets, Chapter 5 on "Filter Design" and Chapter 10 "Structural Drainage," John Wiley and Sons, Inc., 1968.

5. Bertram, G. E., An Experimental Investigation of Protective Filters, S.M. Series No. 7, January 1940, Graduate School of Engineering, Harvard University.

6. Marks, D. B., The Behavior of Aggregate and Fabric Filters in Sub-drainage Applications, University of Tennessee, February 1975, pp. 1-14.

7. Barenberg, E. J., et al, Evaluation of Soil-Aggregate Systems with Marafi Fabric, Report No. UILU-ENG-75-2020, University of Illinois, August 1975.

8. Calhoun, C. C., Compton, J. R. and Strohm, W. E., "Performance of Plastic Filter Cloths as a Replacement for Granular Filter Materials," paper for presentation at Annual Meeting of Highway Research Board, January 1971.

9. Eiland, E. and Lockett, L, "Use of Filter Fabric in French and Trench Subsurface Drains on I-65 in Chilton County, Alabama," paper for presentation at Annual Meeting of the American Association of State Highway and Transportation Officials at Birmingham, Alabama, November 1976.

10. Highway Focus, U.S. Department of Transportation, FHA Administration, Volume 9, No. 1, May 1977.

11. Lambe, T. W. and Whitman, R. V., Soil Mechanics, 1st Edition, 1969, John Wiley and Sons, Inc.

12. McGowan, Alan, "The Properties and Uses of Permeable Fabric Membranes," presented at the workshop on Materials and Methods for Low Cost Road, Rail, and Reclamation Work, Leura, Australia, September 6-10, 1976.

13. Sample Specifications for Engineering Fabrics, U.S. Department of Transportation, FHA Offices of Research and Development, Report No. FHWA-TS-78-211.

14. Sowers, George B. and Sowers, George F., Introductory Soil Mechanics and Foundations, 2nd Edition, 1961, The Macmillan Company.

15. Cedergren, H. R., Drainage of Highway and Airfield Pavements, John Wiley and Sons, Inc., 1974.

APPENDIX A

FLOW CAPACITY OF GEOTEXTILES

Proposed California Method

The following test method is for evaluating flow capability of geotextile fabrics for use in subdrainage applications. The water flow capability when measured as herein described, is consistent with the application configuration and is defined as Flow Capacity. Whereas permeability measures an absolute flow potential, Flow Capacity evaluates flow capability under operational conditions.

APPARATUS AND MATERIALS REQUIRED

1) Horizontal permeameter, with sample holder, see Figure A-1.
2) High volume, 25 gpm, and low constant presure, 2 psi, water source.
3) Spirit level.
4) Constant elevation head reference.
5) Scale, 12 inch, to measure distance from reference to both the entrance head and exit head to nearest 0.1 inch.
6) Flow evaluation media, a stop watch and calibrated catch bucket.
7) Record sheets.
8) Wrenches and screwdriver for assembly and dismantling.
9) Three fabric samples 6 inches in diameter.

PROCEDURE

Three random samples of fabric should be cut from a 3-ft square or larger sample. They may be cut with shears, by hand, from traced outlines or with a heated annulus. A 6-inch I.D. brass annulus kept at 475°F works efficiently on all plastic geotextiles tested to date. The melting type cutting provides a neater, non-fraying uniform edge facilitating sample handling.

Install the first test sample in the concentric ring compression retainer as illustrated in Figure A-2. Assemble the permeameter and sample holder as shown in Figure A-3. Position the permeameter under the water source and above the drain facility, Figure A-4. Level the downstream channel, the portion through which the water leaves the fabric. Initiate water flow in sufficient quantity to completely submerge the inlet side of the fabric sample. Adjust flow to achieve a steady head.

When steady state flow is achieved, the Flow Capacity can be evaluated. Both the inlet head, H1, and the outlet head, H2, are measured as distances from the constant elevation reference. Record as H1(i) and H2(i) on the data sheet, where i is the sample number, i.e., H1(1), H1(2), etc.

Using the calibrated catch bucket, intercept the outlet flow and measure the time required to fill the bucket. Do this three times and record the average value as T(i).

Repeat the above procedure for the second and third samples.

Record the calibrated bucket volume, Q, in gallons and the sample test diameter, D, in inches, the permeameter inside diameter at the sample.

CALCULATIONS

The Flow Capacity is the average value obtained using the three test runs. First calculate the individual Flow Capacities, FC(i), then average these values to determine FC, the Flow Capacity.

Formulae:

$$\Delta H(i) = H1(i) - H2(i)$$

$$A = \pi D^2/4$$

$$FC(i) = \frac{Q(CF)}{T(i)\Delta H(i)A}$$

$$FC = \frac{FC(1) + FC(2) + FC(3)}{3}$$

$CF = 1.66 \times 10^6$ for feet/day

$CF = 2.54$ for centimeters/second

i = the sample number

REPORTING

Report all three FC(i) values and the FC value so the variation is apparent. Also list the respective ΔH values and the cloth brand.

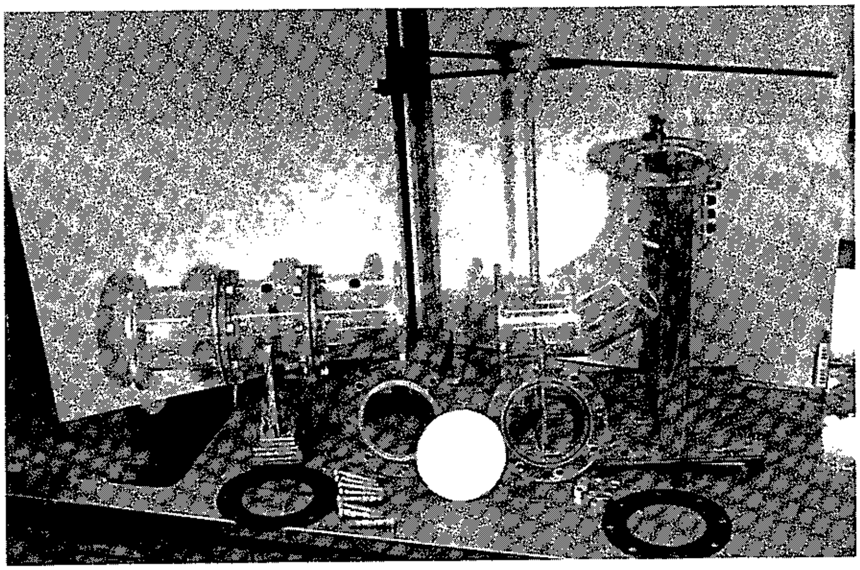
EXAMPLE Fabric Type: Example

H1(i)	H2(i)	T(i)	ΔH(i)	FC(i)
10.7	0.75	29.0	9.95	1617 ft/day
10.55	0.80	28.1	9.75	1703
11.25	1.25	31.1	10.0	1500

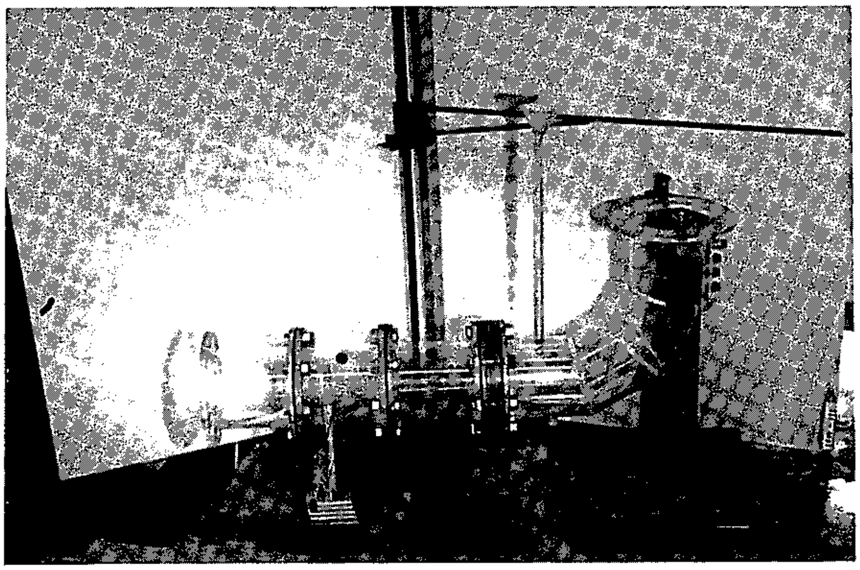
Q = 5.41 gallons

D = 4.95 inches

$$FC = \frac{1617 + 1703 + 1500}{3} = 1607 \text{ ft/day}$$

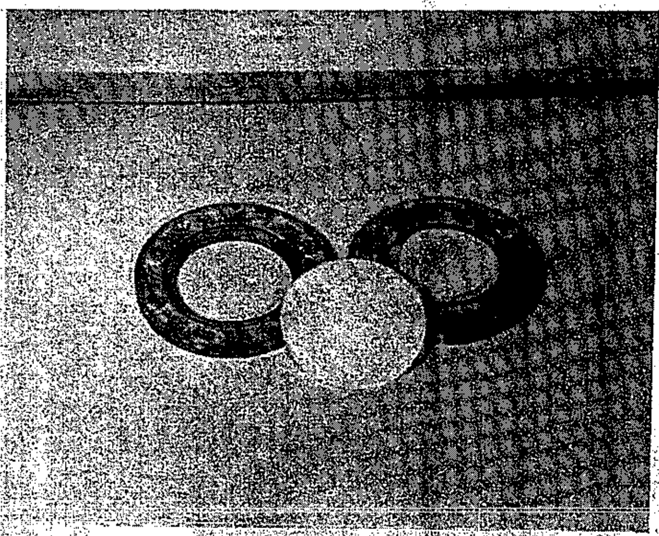


Permeameter, sample holder, gaskets
and sample, the white disc.

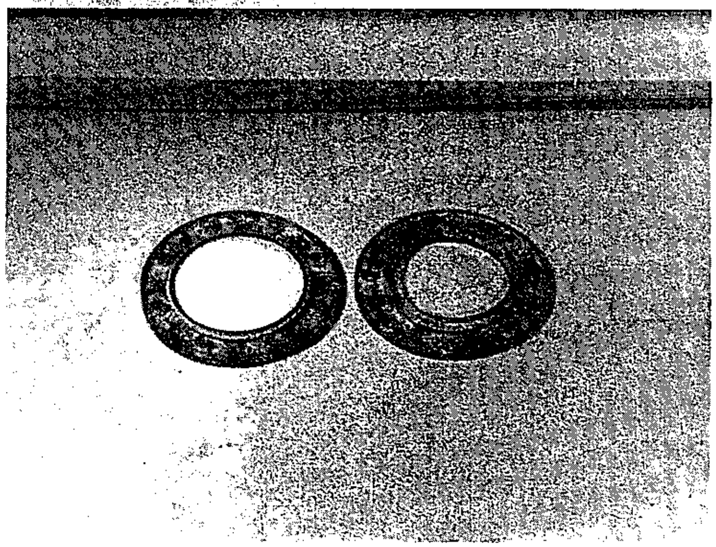


Assembled permeameter and sample holder.

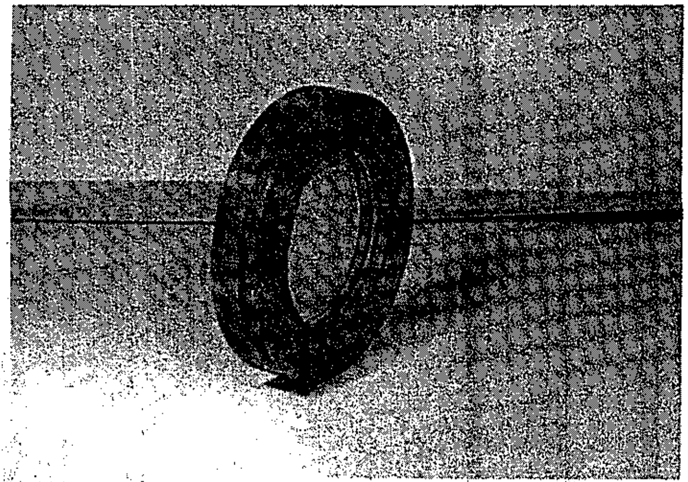
FIGURE A-1 PERMEAMETER WITH SAMPLE HOLDER



Two piece sample holder with sample, white disc.

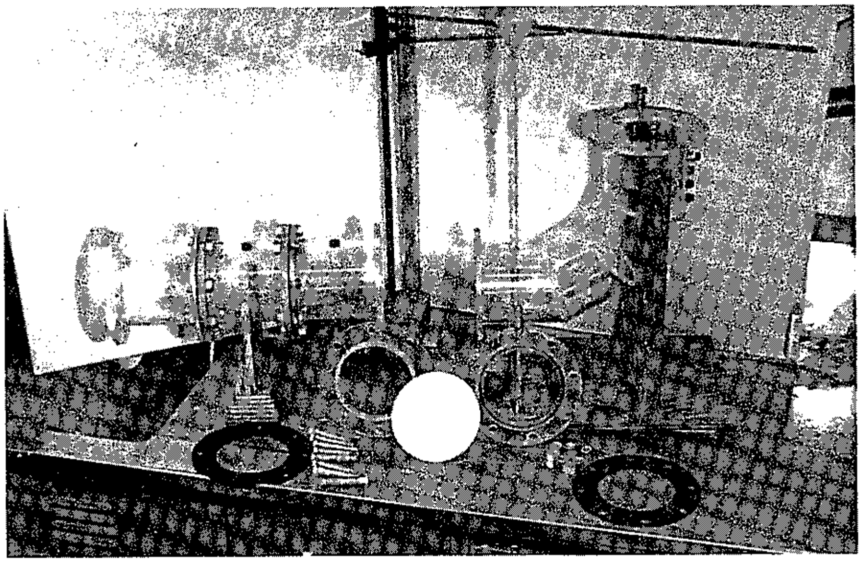


Sample holder with sample inserted into left hand section.

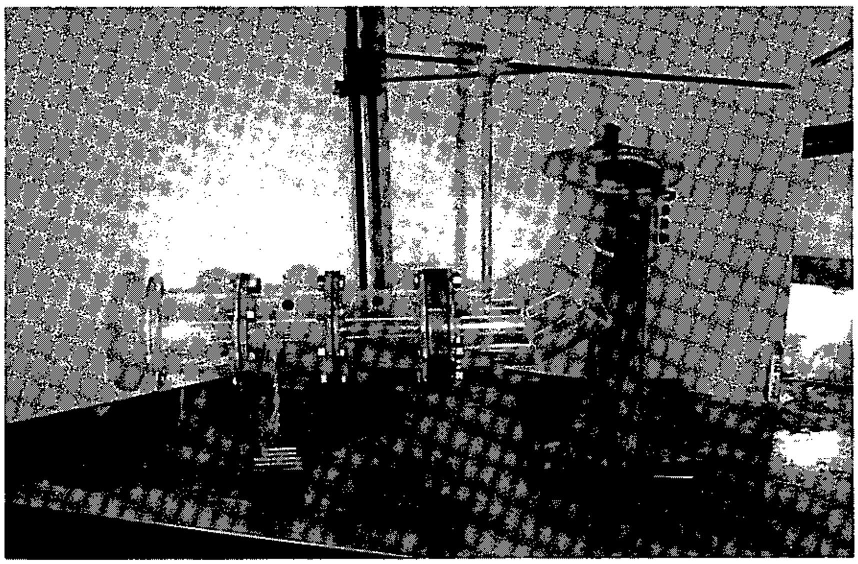


Fully assembled sample holder with sample

FIGURE A-2 SAMPLE HOLDER

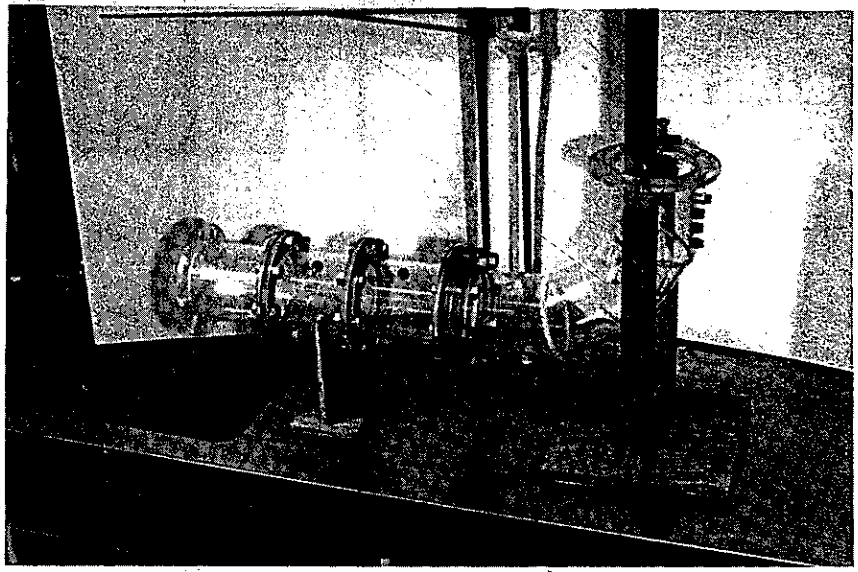


Permeameter with sample holder ready to be assembled.

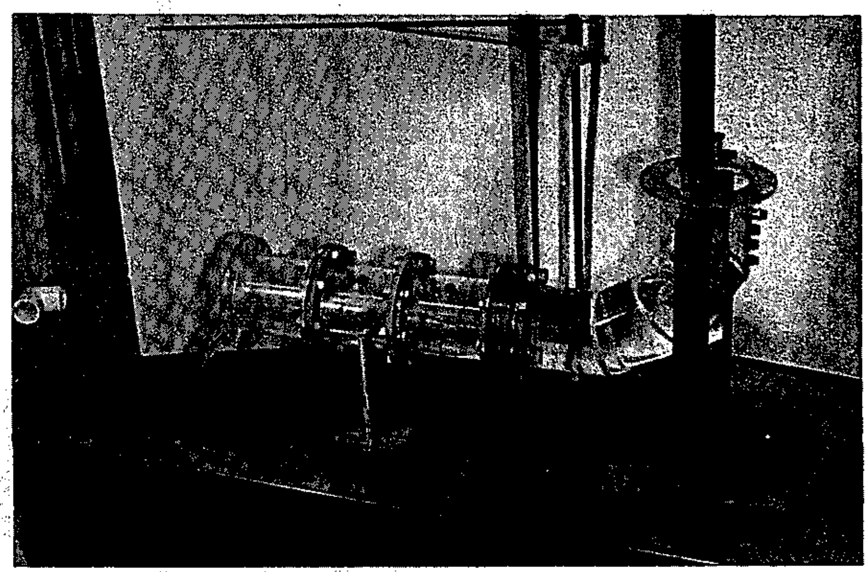


Fully assembled sample holder and permeameter.

FIGURE A-3 SAMPLE HOLDER AND PERMEAMETER ASSEMBLY



Permeameter positioned over drain and
under inflow pipe.



Permeameter with a steady state flow
condition.

FIGURE.A-4 WATER INLET AND DRAINAGE FOR PERMEAMETER

APPENDIX B

PLUGGING FLOW CAPACITY OF GEOTEXTILES

Proposed California Method

PLUGGING FLOW CAPACITY

The following test method, an extension of the Flow Capacity test, is for evaluating the filtration and plugging potential of geotextile fabrics for use in subdrainage systems. This test utilizes glass beads to represent soils requiring drainage and filtration. If the D_{50} and/or D_{85} soil grain sizes are larger than a sieve size range of 60 to 100 and the soil is well graded, the filtration parameter need not be considered for the D_{50} size, only the fabric plugging by the D_{15} size. The D_x grain size is the size D for which x% of the soil is finer than D. If all soil particles are greater than a 60 sieve size, then filtration is probable and plugging unlikely with the nonwoven fabrics tested. Particles finer than the 325 size, clays, normally do not readily dissociate and therefore the tested fabrics should also work with those soils that are essentially composed of these very fine clay particles. The size ranges above and below the 100 to 400 sieve sizes can be evaluated if appropriate size beads are available.

APPARATUS AND MATERIALS REQUIRED

1) Horizontal permeameter, with sample holder, see Figure B-1.
2) High volume, 25 gpm, and low constant pressure, 2 psi, water source.
3) Spirit level.
4) Constant elevation head reference.
5) Scale, 12 inch, to measure distance from reference to both the entrance head and exit head to the nearest 0.1 inch.

6) Flow evaluation media, a stop watch and calibrated catch bucket.
7) Record sheets.
8) Wrenches and a screwdriver for assembly and dismantling.
9) Three samples of the fabric to be tested, 6 inches diameter.
10) Glass beads, sieve size ranges: 60 x 100, 70 x 140, 100 x 200, 140 x 270, 200 x 325, 270 x 1000.

PROCEDURE

Install the first sample in the concentric ring compression retainer as illustrated in Figure B-2. Assemble the permeameter and sample holder as shown in Figure B-3. Position the permeameter under the water source and above the drain facility, Figure B-4.

Level the downstream channel, the portion through which the water leaves the fabric. Initiate water flow in sufficient quantity to completely submerge the inlet side of the fabric sample, leaving ample freeboard. Adjust the flow to achieve a steady head.

When steady state flow is achieved, the Flow Capacity can be approximated. Both the inlet head, H1, and the outlet head, H2, are measured as distances from the constant elevation reference. Record as H1 and H2 on the data sheet.

Using the calibrated catch bucket intercept the outlet flow and measure the time required to fill the bucket. Do this three times and record the average value as T.

After establishing the untreated Flow Capacity, glass beads are introduced into the flow stream. Wash five grams of the glass beads which represent the D_{85} soil size into the flow stream as illustrated in Figure B-5. Adjust to steady state flow, if necessary, and remeasure and record H1(i), H2(i), and T(i), where (i) is the total weight of glass beads introduced; i=5, 10 or 15; i.e., H1(5), H2(5), T(5), H1(10), etc. Add a second five-gram charge of D_{85} size beads. After steady state is again achieved, remeasure and record H1(i), H2(i), and T(i). Add another five grams of the D_{85} size beads and adjust to steady state flow remeasuring and recording H1(i), H2(i), and T(i). (Addition of more than 15 grams of beads becomes a test for bead permeability not fabric flow capacity.) Repeat this entire procedure including the untreated Flow Capacity for the D_{50} and D_{15} glass bead sizes. Use separate record sheets and fabric samples for each size of glass beads.

Record the calibrated catch bucket volume, Q in gallons, and the sample test diameter, D in inches, the permeameter inside diameter at the sample.

CALCULATIONS

The Flow Capacity, FC, is approximated using H1, H2, and T in the PFC(i) equation in place of H1(i), H2(i), and T(i) respectively. The Plugging Flow Capacity, PFC, is calculated for each bead size and designated by the soil size represented. A PFC_{15}, a PFC_{50}, and a PFC_{85} are calculated. The PFC value used is the minimum calculated for the given bead size. Three PFC values are calculated, one for each five gram addition of beads, for each grain size tested.

Formulae:

$H(i) = H1(i) - H2(i)$ CF = 1.66×10^6 for feet/day

$A = D^2/4$ CF = 2.54 for centimeters/second

$$PFC(i) = \frac{Q(CF)}{T(i)\ H(i)A}$$

PFC_{15} = the minimum value of PFC(i) when using the D_{15} grain size equivalent glass beads.

PFC_{50} = the minimum value of PFC(i) when using the D_{50} grain size equivalent glass beads.

PFC_{85} = the minimum value of PFC(i) when using the D_{85} grain size equivalent glass beads.

i = the sample identification, the total weight of glass beads added to that time (5, 10 or 15).

REPORTING

The PFC_{15}, its respective PFC(i) values and corresponding heads should be listed. A similar listing for the PFC_{50} and PFC_{85} should also be reported as well as the FC approximations. The D_{15}, D_{50}, and D_{85} size glass beads used should be listed and the fabric type and brand should be presented.

EXAMPLE

Fabric Type: <u>Example</u>, D_{85}, <u>60-100</u>; D_{50}, <u>100-200</u>; D_{15}, <u>200-325</u>

PFC(o) = FC approximation

	i	H1(i)	H2(i)	ΔH(i)	T(i)	PFC(i)
	0	17.6	12.4	5.2	15.4	5827 ft/day
D_{85} Size	5	17.6	10.6	7.0	15.4	4329
	10	17.7	8.2	9.5	15.7	3129
	15	17.7	6.1	11.6	16.3	2468

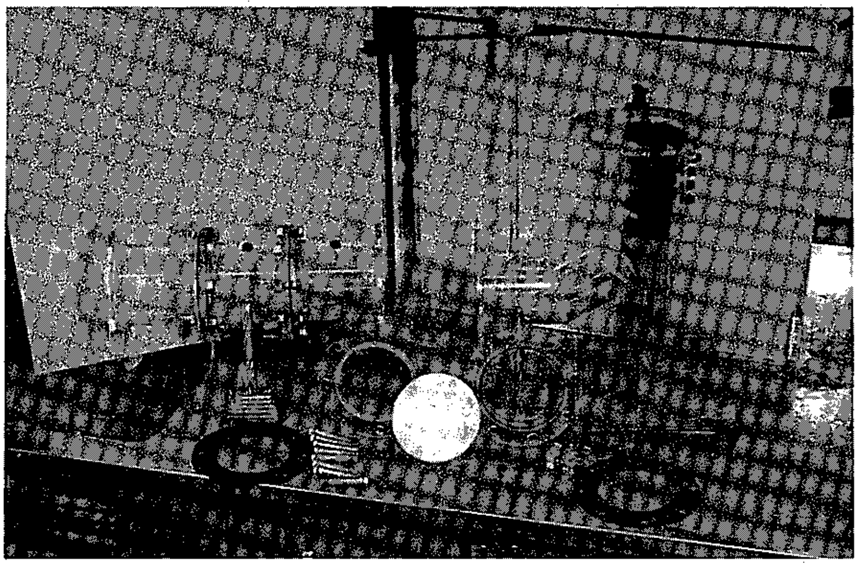
PFC_{85} = 2468 ft/day

	i	H1(i)	H2(i)	ΔH(i)	T(i)	PFC(i)
	0	17.7	12.8	4.9	16.0	5952
D_{50} Size	5	17.7	9.4	8.3	16.4	3428
	10	17.7	5.1	12.6	20.5	1807
	15	17.85	7.8	10.05	49.0	948

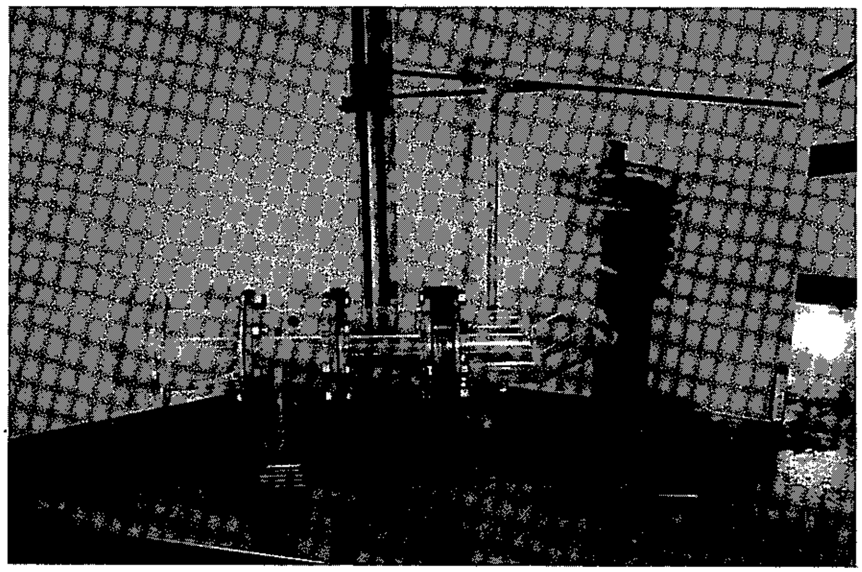
PFC_{50} = 948 ft/day

	i	H1(i)	H2(i)	ΔH(i)	T(i)	PFC(i)
	0	17.7	12.4	5.3	15.5	5680
D_{15} Size	5	17.7	9.1	8.6	16.0	3391
	10	17.6	5.7	11.9	20.9	1876
	15	17.8	6.1	11.7	43.8	910

PFC_{15} = 910 ft/day

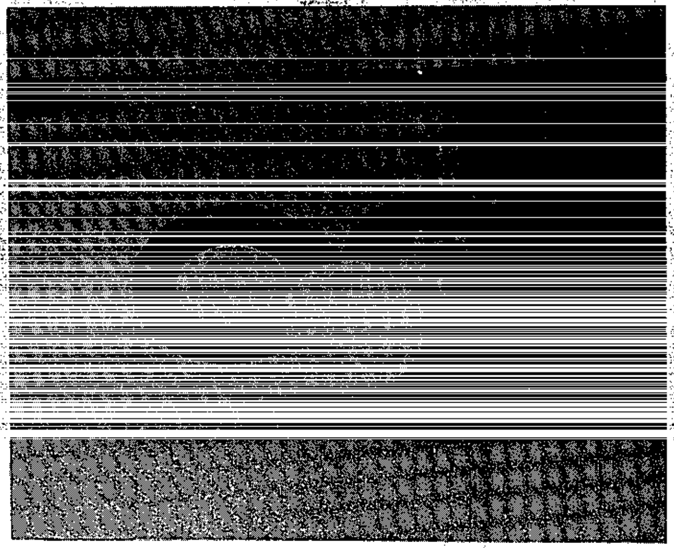


Permeameter with sample holder, gaskets and sample, the white disc.

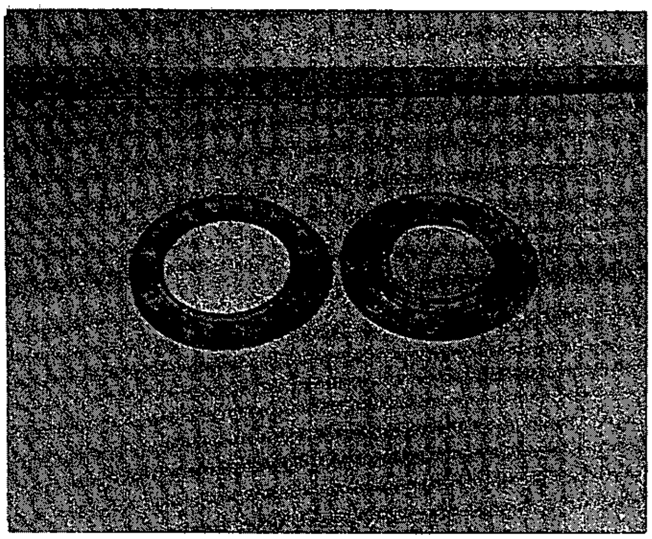


Fully assembled permeameter and sample holder.

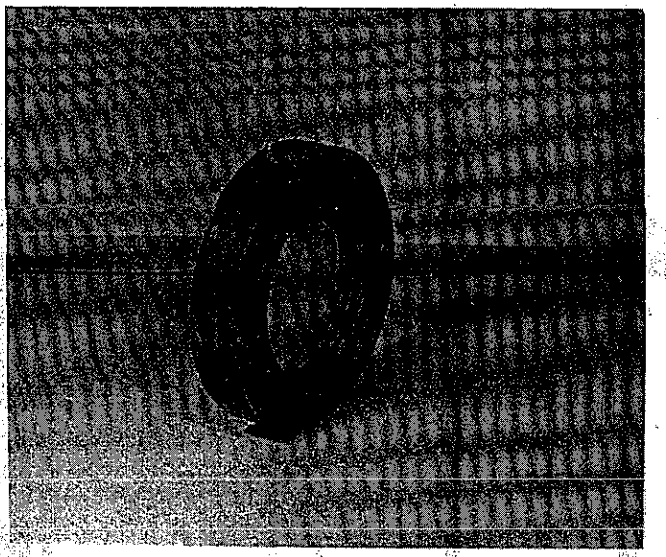
FIGURE B-1 PERMEAMETER WITH SAMPLE HOLDER



Two piece sample holder with sample, white disc.

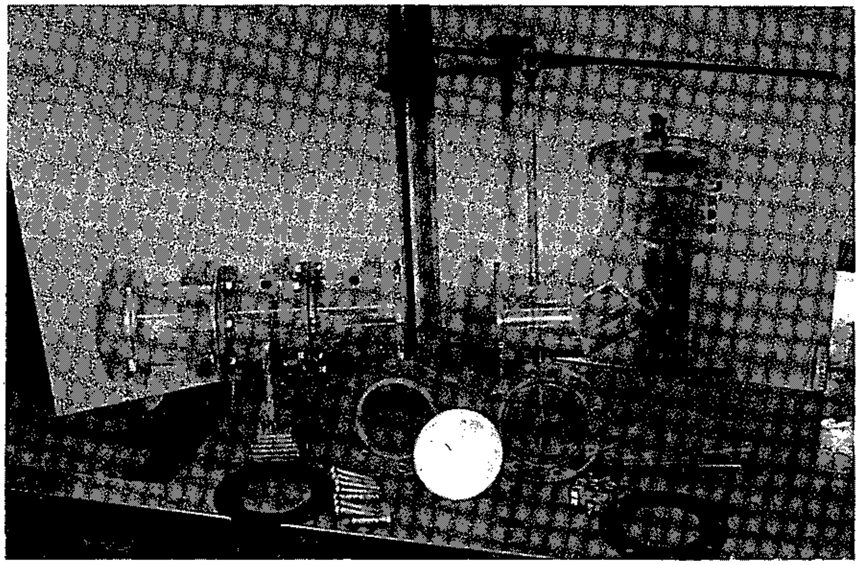


Sample holder with sample inserted into left hand section.

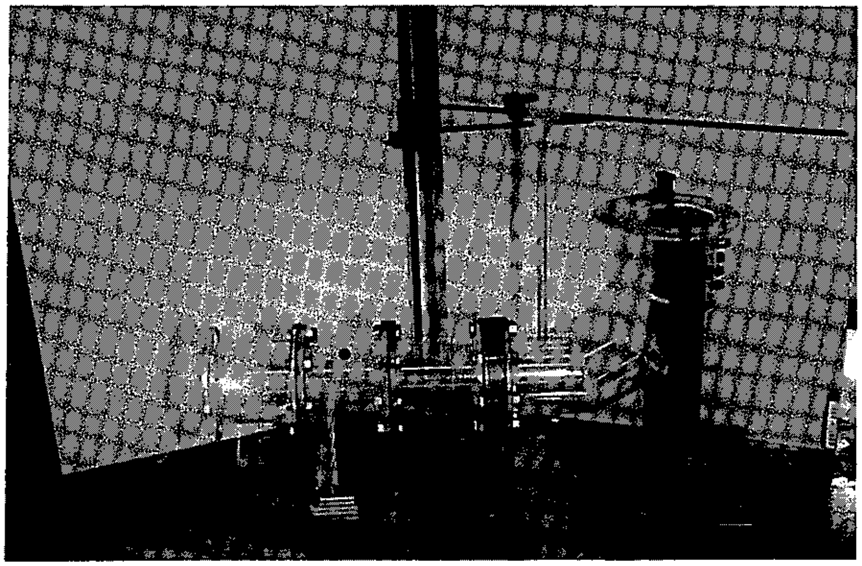


Fully assembled sample holder with sample.

FIGURE B-2 SAMPLE HOLDER

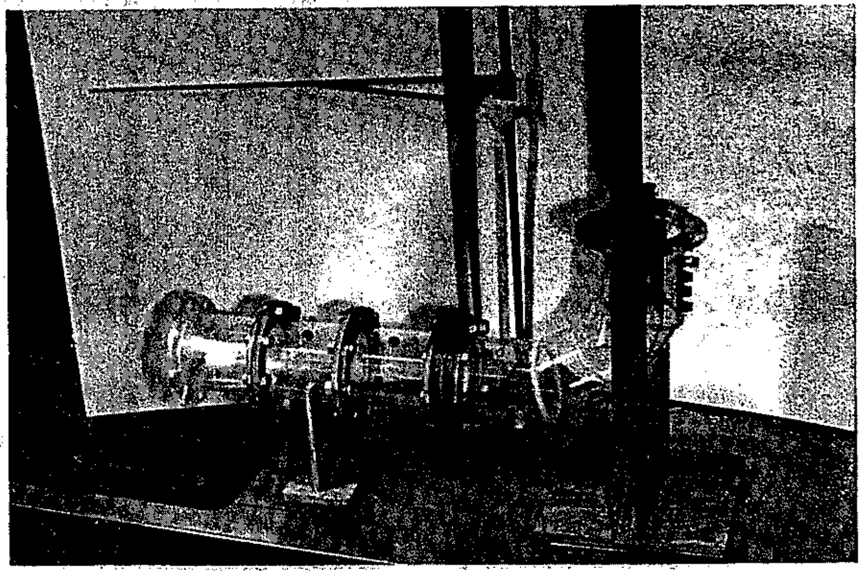


Sample holder and permeameter, ready for assembly.

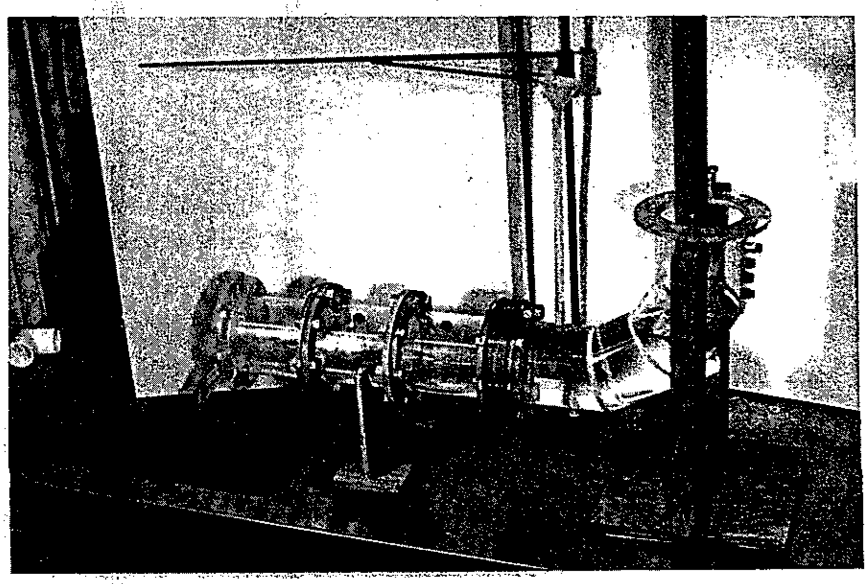


Fully assembled permeameter and sample holder.

FIGURE B-3 SAMPLE HOLDER AND PERMEAMETER ASSEMBLY

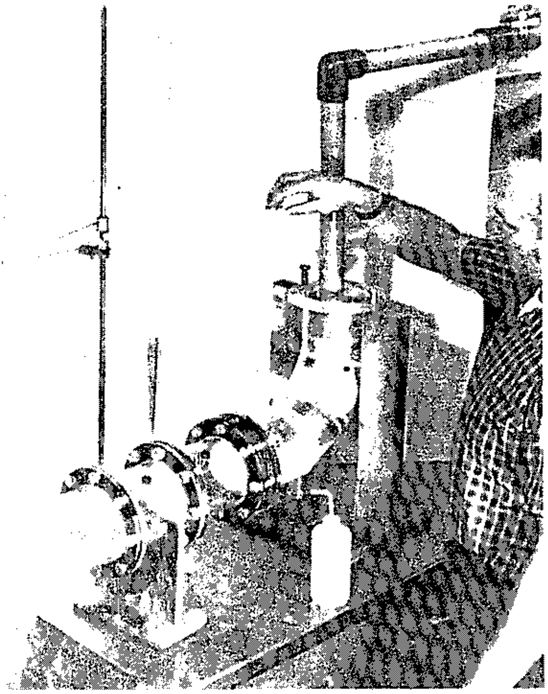


Permeameter positioned over drain and under water inflow pipe.

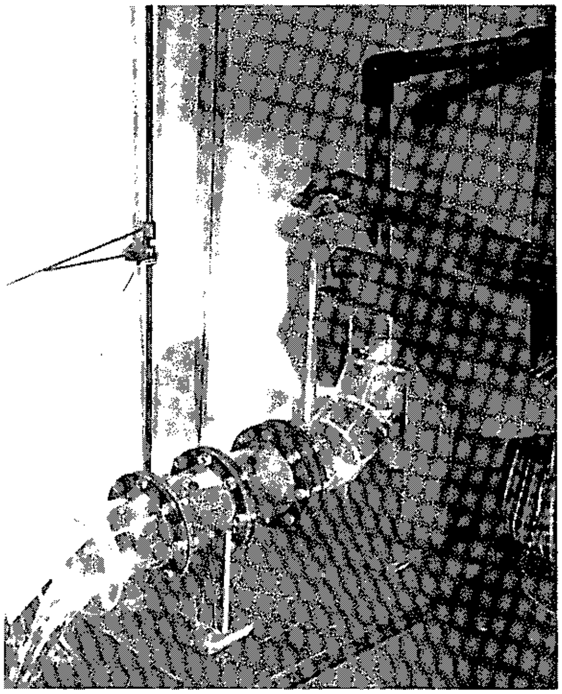


Permeameter with a steady state flow condition.

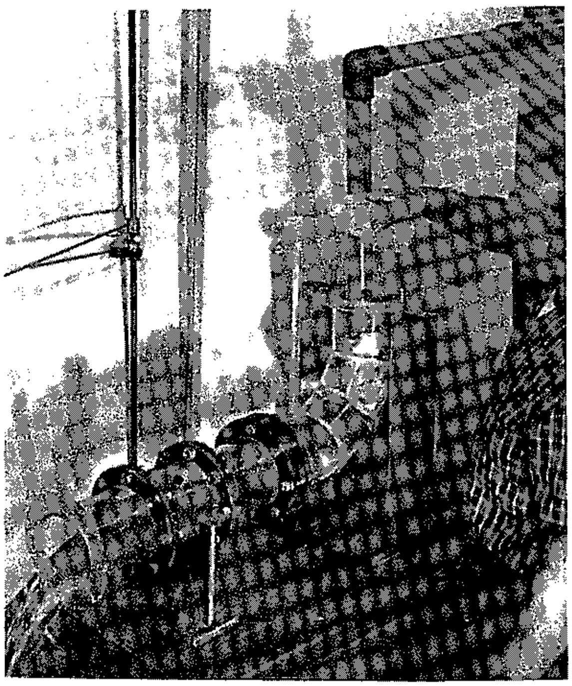
FIGURE B-4 WATER INLET AND DRAINAGE FOR PERMEAMETER



Pouring in premeasured glass beads.



Washing beads out of vial.



Thoroughly washing funnel and introduction tube to assure total bead introduction.

FIGURE B-5 GLASS BEAD INTRODUCTION